ARIZONA DEPARTMENT OF TRANSPORTATION

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# SAFETY EFFECTS OF TRAFFIC SIGNAL INSTALLATIONS

## State of the Art

**Final Report**

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16. ABSTRACT

This state-of-the-art report provided a comprehensive review of signal installations and their impacts on accident patterns, and accident frequency and severity. It contained information on accident statistics by type and severity, accident rates for stop controlled and signalized intersections, accident patterns on arterials, and accident statistics for different signal types. Pedestrian safety due to signal installation was also addressed.

The report documented factors affected by signal installations such as intersection capacity, vehicular delays, and vehicular fuel consumptions. The economics of installing signals was addressed, and a summary of international experience with signal installation was provided. A work plan for further research needed in this area was documented.

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## 1. INTRODUCTION

Traffic signal control is the most common type of control used at heavily traveled intersections in urban areas. The literature defines a traffic control signal as any power-operated traffic control device, whether manually, electrically, or mechanically operated, by which traffic is alternately directed to stop and permitted to proceed (1).

It was reported that the world's first traffic signal using colored light was installed in 1868, at the intersection of George and Bridge Streets in London, England (2). At the beginning of the 1930's a first attempt at vehicular control of signals was made in the United States by placing microphones at the side of the road and requesting drivers to sound their horns.

Over the years, traffic control signal development has experienced dramatic changes. The advent of computer technology, solid state electronics, and the micro-chip industry has resulted in manufacturing flexible equipment to permit the implementation of virtually any conceivable control strategy and reliability to operate under extreme conditions with no malfunctioning. The electronic industry has also witnessed equivalent advancements in vehicular detection and data transmission. In the area of vehicular detection, state of the art inductive loop detectors are being used. As for data transmission, fiber optics have been used in large scale signal control systems in this country.

A great deal of research has been carried out to help the traffic engineer in designing suitable traffic-signal schemes and in setting signals to minimize delays. Much practical experience has also been gained by engineers working in the field over the last forty years or so. Unfortunately, after all these years of experience and countless evaluation studies, it is not clear what its safety impact is. It is true and logical that signal installation increases rear-end accidents and decreases right-angle accidents, a finding that was reached by all previous investigations. However, the overall effectiveness of signal installations and their timings would appear to depend on some other factors. Such factors are intersections capacity, vehicular delays, vehicular fuel consumptions, and signal cost installation and maintenance.

This report attempts to provide a more comprehensive treatment of the subject than what has already been published previously. It contains a thorough literature research, briefly highlights the major findings of previous efforts, and finally recommends a work plan for further research needed in this area.

## 2. RESEARCH OBJECTIVES

The objective of this study is to prepare a state-of-the-art report and develop a research work plan for any recommended research.

The following tasks were performed:

1. Critically review all available studies on the safety effect of traffic signal installation, to extract useful relevant information, and to identify those studies which might provide useful data.
2. Prepare and submit a state-of-the-art report on safety effects of traffic signal installation which at minimum address the following:
   a) Data needs and their required format at variety of intersections and types of traffic signal arrangements to analyze the traffic signal effects.
   b) Evaluation of positive and negative effects of a variety of traffic signal systems on the accident history.
   c) Evaluation of the pedestrian safety due to different types of intersection signalization.
   d) Economic aspects of traffic signal installation as related to traffic flow safety, capacity, and delay.
3. Develop a detailed work plan for any recommended research, and establish the anticipated project duration and estimated budget.

## 3. BACKGROUND INFORMATION

Warranted and properly designed traffic control signals may reduce the frequency of certain types of accidents (right-angle type), affect orderly traffic movement, provide for continuous flow of platoon of vehicles along a route, allow pedestrians to cross a heavy traffic stream, and control traffic more economically than by manual methods. On the other hand, unwarranted, improperly operated traffic signals may cause increased accident frequency, excessive delay, disregard of signal indications, and circuitous travel on alternate routes.

Traffic signals, in general, impact the safety and the effectiveness of traffic flow on facilities. The safety aspect can be measured by accident rate classified by type of accidents and accident severity. Experience has indicated that although the installation of signals may result in a decrease in the number of right-angle accidents, it will, in most cases, result in an increase in rear-end accidents with the total number of accidents remaining essentially unchanged. The severity of accidents is more apparent at high speed intersection approaches. Studies have shown that by using signal activated controllers with advanced detection systems on the high speed facility, the number and the severity of accident are usually reduced. The idea behind this system is to detect the location of the approaching vehicles immediately before the signal turns to amber, and extend the green phase as needed. By doing so, the probability of rear-end accidents is decreased, however, delay to vehicles waiting on opposing phases is increased. Detailed information regarding these studies will be discussed in the literature research section of the report.

As far as the effectiveness of traffic flow is concerned, installing traffic signals affects traffic delay and intersection capacity. Numerous studies have attempted to develop warrants based on traffic delay only. The idea is to determine the minimum vehicular volumes on main and side streets needed to produce equal average delay per vehicle for stop-controlled and signal-controlled intersections. In other words, it is the minimum vehicular volume that will cause the same average delay per vehicle to switch from a two-way stop control to a traffic signal control.

The installation of signals may not only increase overall delay, but also reduce intersection capacity. Therefore, is it important that an experienced engineer should conduct a thorough study of traffic and roadway conditions before considering installing a signal and selecting the needed equipment. The signal should be installed only if the net effect, balancing benefits versus costs, is to the public's advantage.

It is apparent that a system of establishing the need for a signal installation at a particular location is necessary. Such a system is known as signal warrants. The Manual on Uniform Traffic Control Devices (3) provides eleven warrants to determine the needs for traffic control signals. Four of these warrants are volume related, two are signal systems related, one is accident related, one is pedestrian related, one school crossing relation, one is delay related, and one is a combination of warrants.

Several type of traffic signal controllers are available to the traffic engineer. The selection of the proper type for a particular intersection depends on the geometric layout, the nature of approaching traffic, and the spatial relationship with adjacent intersections (4). The most commonly used types of controllers are: pretimed, semiactuated, fully actuated, and master controllers.

A pretimed controller operates according to fixed timing plans. Time plans include cycle length, phase sequence and durations. It is usually used where there are predictable and stable traffic volumes or in a coordinated interconnected system. Where traffic volumes fluctuate widely by cycle and time of the day, actuated controllers are most useful. A semiactuated controller provides a continuous green indication on the major street except when demands occurs on the minor street. Therefore, detectors are placed on the minor street (vehicular detectors or pedestrians pushbuttons). A fully actuated controller permits the adjustment of the various green intervals on the basis of traffic volumes, in which vehicle detectors are placed on all intersection approaches. For controller units controlling more than two traffic phase, the unit can omit or skip unwanted phases. A traffic actuated controller of the volume-density type provides additional features that provide better system efficiency in terms of fewer delays and more throughput.

A master controller unit is used to supervise and coordinate the operation of one or more intersection controller units in a system. A communication medium is required to receive traffic data from sampling detectors and to transmit supervisory and coordination commands to the intersection controller units. Traffic responsive masters are more flexible in that system pattern changes are initiated by changes in traffic flow rather than on a time basis.

## 4. LITERATURE REVIEW

This section is divided into five major sections. The first section reports on the vehicular safety aspects of signal installation. The second section is aimed at pedestrian safety at signalized intersections. The third section addresses the issues of delay, fuel consumption and capacity for signalized intersections, and the fourth section is aimed at the economics of installing signals. The fifth section reviews the international experience with signal installations.

The first section is divided into four subsections to specifically address accident statistics as reported in the literature for: 1) accident type and accident severity; 2) stop controlled intersections and signalized intersections; 3) arterials and expressways; 4) signal control types.

## 4.1 Vehicular Safety:

### 4.1.1 Accident Statistics by Type and Severity

The intention of this section is to provide the reader with accident statistics related to type (rear-end, right-angle, side-swipe, etc.) and related to severity (property damage, personal injury, and fatalities).

An early study attempted to quantify area wide impact of traffic control devices in the Philadelphia area (5). Table 1 documents percentages of accidents for two-way stops, four-way stops, and signalized intersections cross-classified by accident severity, and accident type. Closer examination of this table reveals that for these selected locations in Philadelphia, property damage represented the highest severity class percentage, and that pedestrian accidents represented a constant value of 12% for all types of controllers. Right-angle accidents was the predominant type for four-way stop control.

In a previous study documented in the National Cooperative Highway Research Program Report [NCHRP] number 233 (6), accident rates per year for signalized intersections were documented for two locations, Skokie, IL, and Los Angeles, CA. These accident rates are shown in Table 2 and Table 3 for Skokie, and Los Angeles, respectively. Two general observations can be pointed out; the first observation is that there is a clear correlation between the average daily traffic and both accident numbers and accident rates. The second observation is that accident rates at signalized intersections, in general, have an accident rate range of 0.55-2.50 accidents per million entering vehicles.

### 4.1.2 Stop Controlled Versus Signalized Intersections:

The topic of replacing stop sign control with signal control has been the center of attention for numerous studies. In this section, an attempt was

TABLE 1. PERCENTAGES OF ACCIDENTS FOR EACH TRAFFIC CONTROL MODE

| | | SEVERITY | | | | TYPE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Control | Property Damage | Personal Injury | Ped. | Fatality | RT Angle | Rear End | Fixed Obj | Side Swipe | Ped. | AADT* |
| S. Phila. | Traffic Signals | 70 | 18 | 12 | 0 | 26 | 24 | 31 | 7 | 12 | 6700 |
| | Two-Way Stops | 68 | 20 | 12 | 0 | 51 | 12 | 20 | 5 | 12 | 4400 |
| | Four-Way Stops | 77 | 11 | 12 | 0 | 23 | 17 | 40 | 8 | 12 | 6200 |
| N. Phila. | Traffic Signals | 68 | 20 | 12 | 0 | 33 | 23 | 22 | 10 | 12 | 6900 |
| | Two-Way Stops | 69 | 19 | 12 | 0 | 50 | 10 | 22 | 6 | 12 | 4400 |
| | Four-Way Stops | 79 | 8 | 13 | 0 | 17 | 17 | 44 | 9 | 13 | 3600 |

Source: Reference Number 5

*AADT = Annual Average Daily Traffic

TABLE 2. ACCIDENT RATES PER YEAR FOR SIGNALIZED INTERSECTIONS IN SKOKIE, IL.

| Entering ADT | 11000-16000 | 16000-21000 | 21000-26000 | 26000-31000 | 31000-36000 | 36000 41000 |
|---|---|---|---|---|---|---|
| Avg. Accident Per Year | 7.5 | 10.3 | 18.1 | 20.6 | 30.6 | 33.8 |
| # of Intersections | 8 | 13 | 35 | 41 | 41 | 10 |
| Change of Frequencies | 3-13 | 3-18 | 5-30 | 3-73 | 12-60 | 14-61 |
| Avg. Annual Accident Rate Per Intersection* | 1.52 | 1.52 | 2.11 | 1.98 | 2.5 | 2.40 |

*Accident rate per million vehicles calculated for the mid point of entering ADT.

Source: Reference Number 6

TABLE 3. ACCIDENT RATES FOR SIGNALIZED INTERSECTIONS IN LOS ANGELES, CA.

| ADT | | # of | Avg. Annual Accident Rate | Standard |
|---|---|---|---|---|
| Major | Minor | Intersections | Per Intersection | Deviation |
| 0-3200 | 0-6000 | 170 | 0.55 | 0.38 |
| 6000-32000 | 6000-10000 | 56 | 0.74 | 0.39 |
| 10000-32000 | 10000-14000 | 25 | 0.95 | 0.44 |
| 14000-32000 | 14000-26000 | 17 | 1.20 | 0.31 |

Source: Reference Number 6

made to document the effects of traffic signal installation on traffic accidents. Most of the research attempts listed here use the before and after approach.

In an early study conducted by the Michigan Department of Transportation, before and after accident data was collected for 52 new traffic signal installations and 75 new flasher installations for urban and rural truckline highways (7). The study concluded that total accidents increased by 33%, fatalities dropped from 9 to 3, and total injuries went up from 345 to 389. Furthermore, it was concluded that flashers decreased accidents. Table 4 contains statistics for both signal installations and flasher installations.

In an attempt to relate accident patterns to type of intersection, a study was conducted, and a large number of different measures of effectiveness that describe changes in accident patterns were compiled (8). Analysis of variance and regression techniques were utilized to show that this relationship should be described by complex models rather than by a simple signal-no-signal division. Hypothesis testing concluded that signalization showed no evidence of a significant decrease in net accident related disutility, especially for signals not warranted by traffic volume. Table 5 documents the statistical results of the before and after data. As expected, an increase in rear-end accidents [180%] and reduction in right-angle accidents [34%] occurred due to signal installation.

In another study, two signal installations were assessed in terms of safety responsiblity, acceleration and speed requisites and adequate road engineering (9). The results indicated that due to signal installations, right-angle accidents decreased, rear-end and miscellaneous accidents increased, and overall accident rate did not change significantly. It was also concluded that in order to improve the accident rate, an intersection must have a high traffic volume, a high existing accident rate, and a complex geometric configuration before signalization becomes effective.

A recent effort attempted to evaluate the effect of traffic signal installations on accidents (10). A before and after study of 31 recently signalized intersections was conducted in Milwaukee, Wisconsin. The major findings of this study were: 1) upon signalization, little or no change was noted overall either in number of accidents or in severity; 2) right-angle accidents decreased significantly [34%]; 3) rear-end accidents increased significantly [37%]; 4) other accidents increased significantly [41%]; 5)

TABLE 4. NUMBER OF ACCIDENTS FOR SIGNAL INSTALLATION AND FLASHER INSTALLATIONS

| | Signal Installation* | |
|---|---|---|
| Accident Type | Before | After |
| Right-Angle | 242 | 134 |
| Rear-End | 259 | 514 |
| Left-Turn | 35 | 58 |
| Other | 85 | 125 |

| | Flasher Installation** | |
|---|---|---|
| Accident Type | Before | After |
| Right-Angles | 241 | 179 |
| Rear-End | 64 | 54 |
| Left-Turn | 130 | 117 |
| Rear-End due to right turner | 14 | 5 |
| Ran-off-Road | 71 | 33 |
| Other | 58 | 46 |

*Recorded Since Sept. 21, 1953

**Recorded Since Jan., 1950

Source: Reference Number 7

TABLE 5: BEFORE AND AFTER STATISTICAL RESULTS

| | Number of Accidents | | | |
|---|---|---|---|---|
| Classification | Before | After | Percent Change | Significance |
| **SEVERITY OF ACCIDENT** | | | | |
| Fatality | 9 | 3 | -66.7 | ---[a] |
| Injury | 218 | 179 | -17.9 | ---[a] |
| **TYPE OF ACCIDENT** | | | | |
| Rear-End | 89 | 250 | +180.9 | C |
| Right-Angle | 255 | 168 | -34.1 | C |
| Turning Movement | 31 | 36 | +16.1 | N |
| Pedestrian | 3 | 7 | +133.3 | N |
| Head-On | 3 | 3 | --- | - |
| Misc. | 30 | 45 | +50 | C |

[a]- Not Applicable

N- Not Significant

C - Conservative Test (Chi-Square Test)

L - Liberal Test (Poisson Distribution)

Source: Reference Number 8

vehicle/pedestrian and opposing direction accidents did not change appreciably. Tables 6 and 7 report on accident changes by type and by severity. The study concluded that, in general, signalization is not a reliable accident reduction measure but it does not produce a significant increase either.

Traffic signal removal has been evaluated in terms of traffic safety. A study attempted to evaluate five intersections after signals were replaced by stop signs (11). The analysis concluded that at low volume signalized intersections, an insignificant change in accidents is expected if the signal is removed. Therefore, where it is not warranted, signals should be removed from that particular intersection.

In a more comprehensive study, over 200 intersections in 31 political entities within the U.S. were investigated to determine the criteria of signal removal (12). For 26 intersections converted to multi-way stop control, annual accident frequency dropped from 1.70 to 0.68 accidents per year [a 60% reduction]. Annual injury accident frequency per year dropped from 0.50 to 0.19 for intersections converted to 2-way stop control [191 intersections], total accidents per year dropped from 2.46 to 2.38 and injury accidents per year from 0.70 to 0.63. Right-angle accidents increased 51% and rear-end accidents decreased 49% at these 191 converted intersections.

### 4.1.3 Accidents on Arterials and Expressways

In an effort to quantify benefits and costs of expressways, a study was conducted to investigate the safety of arterial and expressway traffic in Chicago (13). The study concluded the following: 1) 100,000 vehicles traveling 100,000 miles on an expressway can have 389 fewer accidents than the same traffic traveling the same distance on an arterial [the breakdown of the 389 accidents is: 290 property damage, 98 injury accidents, and 1 fatality]; 2) for the same criteria, it was estimated that an annual saving of $160,000 can be achieved; 3) accident rates are higher near the central core of the city and decrease towards the city limits; 4) accident rates are affected by street design characteristics. On the average, accidents rates per million vehicles of travel were found to be 14.3 and 2.8 for arterials and expressways, respectively.

TABLE 6. ACCIDENT CHANGES BY TYPE OF ACCIDENT

| | Before | | | After | | | Percent Change | |
|---|---|---|---|---|---|---|---|---|
| | # of Accident | | Severity Index (S.I) | # of Accidents | | SI | After Minus Before | |
| Type of Accident | Actual | PDOE | PDOE / Actual | Actual | PDOE | PDOE / Actual | Actual | PDOE |
| Right Angle | 264 | 409 | 1.55 | 178 | 319 | 1.79 | *-33% | *-22% |
| Rear Eng | 160 | 186 | 1.16 | 224 | 275 | 1.23 | *+40% | *+48% |
| Opp. Dir. One left | 32 | 53 | 1.66 | 41 | 62 | 1.51 | +28% | +17% |
| Vehicle/ Pedestrian | 18 | 74 | 4.22 | 12 | 40 | 3.33 | -33% | *-47% |
| Other | 46 | 63 | 1.37 | 67 | 101 | 1.51 | *+46% | *+60% |
| Total | 520 | 787 | 1.51 | 522 | 797 | 1.53 | +0.4% | +1.3% |

*Change is consider statistically Significant

PDOE = Property Damage only Equivalent

Source: Reference Number 10

TABLE 7. ACCIDENT CHANGES BY SEVERITY

| Highest Level Of Severity | Number of Accidents | | Percent Change |
|---|---|---|---|
| | Before | After | After Minus-Before |
| Fatal | 2 | 1 | -50% |
| Type A Injury | 12 | 17 | +42% |
| Type B Injury | 62 | 43 | -31% |
| Type C Injury | 61 | 93 | *+52% |
| Property Damage Only | 383 | 368 | -4% |
| Total | 520 | 522 | +0.4% |

Type A - Incapacitating Injury

Type C - Possible Injury

Type B - Non-Incapactating Injury

*Change is considered statistically significant

Source: Reference Number 10

#### 4.1.4 Signal Control Types and Traffic Accidents

This section reports on experiences with different types of signal controllers and their safety aspects. The NCHRP study documented in report number 233 (6) provided accident statistics stratified by control type, and they are documented in Table 8. Closer examination of this table indicates the following:

1) Mean accidents per year for unsignalized intersections are half of those for signalized intersections.
2) Pretimed and volume density controls have lower mean accidents than actuated controllers.
3) As expected, right-angle accidents constitute the major percentage of unsignalized intersection accidents, and rear-end accidents constitute the major percentage of signalized intersection accidents.

The statistics shown in Table 8 are for accident number only and no mention was made of accident rates. The issue of traffic control type and of possible impact on accident rates is worth future investigation.

The dilemma that most drivers face is whether to stop or drive through the intersection during the amber phase on high speed facilities. The location of the vehicle on set of the amber phase with respect to the stop bar has a significant effect on the driver's decision. Experimentation with traffic actuated Green Extension Systems (GES) signals was conducted. The idea behind these systems is to install a group of detectors upstream of the stop bar within the dilemma zones to detect vehicle presence on set of the amber phase and extend the green phase. By doing so, the probability of rear-end accidents caused by the rapid deceleration of the vehicle is significantly reduced.

An early study attempted to evaluate GES in terms of their effectiveness in reducing the dilemma zone problem associated with high speed intersections (14). Before and after studies showed a 54% reduction in total accidents and a 75% reduction in rear-end accidents. The results revealed that accident severity was unaffected. The results of the before and after studies classified by accident type and accident severity are documented in Tables 9 and 10.

A study aimed at evaluating alternatives for detector placement at high speed intersections used traffic conflict as the safety measure of

TABLE 8. SAMPLE STATISTICS FOR DATA STRATIFIED BY CONTROL TYPE

| Type of Control | # of Intersections | #of Accidents/YR | Mean Accident/Yr Per Intersection | % Rear-End | % Right Angle | Confidence Interval at = 0.05 |
|---|---|---|---|---|---|---|
| Not Signalized | 65 | 571 | 8.78 | 26 | 74 | 6.85, 10.71 |
| Pretimed | 126 | 2054 | 16.30 | 54 | 46 | 13.81, 18.79 |
| Semi-Actuated | 37 | 862 | 23.30 | 62 | 38 | 16.15, 30.45 |
| Full-Actuated | 29 | 638 | 22.00 | 69 | 31 | 14.68, 29.32 |
| Volume Density | 5 | 84 | 16.80 | 66 | 24 | 11.70, 21.90 |
| Total | 2622 | 4209 | 16.06 | -- | -- | --- |

Source: Reference Number 6

TABLE 9. CLASSIFICATION OF ACCIDENTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEMS (3 LOCATIONS)

| | Accidents | | Accidents Per Year | |
|---|---|---|---|---|
| Type of Accident | Before (8.5 yrs) | After (3.7 yrs) | Before | Before |
| Rear-End | 28 | 3 | 3.3 | 0.8 |
| Right-Angle | 33 | 10 | 3.9 | 2.7 |
| Sideswipe | 4 | 0 | 0.5 | 0.0 |
| Other | 5 | 1 | 0.5 | 0.3 |
| Total | 70 | 14 | 8.2 | 3.8 |

Source: Reference Number 14

Table 10. Severity of Accidents Before and After Installation of Green-Extension System (3 Locations)

| | Accidents | | Accidents Per Year | |
|---|---|---|---|---|
| Type of Accident | Before (8.5 yrs) | After (3.7 yrs) | Before | Before |
| Property Damage | 45 | 10 | 5.3 | 2.7 |
| Injury | 23(44)* | 4(6) | 2.7(5.2) | 1.1(1.6) |
| Fatal | 2(3) | 0(0) | 0.2(0.4) | 0(0) |
| Total | 70 | 14 | 8.2 | 3.8 |

*( ) - Number of injuries

Source: Reference Number 14

effectiveness (15). Two sites were observed, and a before and after study was conducted at both sites to determine rear-end traffic conflicts. Results showed that the GES caused a reliable reduction of traffic conflicts by 84% at one location and 49% at the second location.

### 4.2 Pedestrian Safety

Observations of pedestrian crossings at urban intersections were made to determine the effectiveness of pedestrian signals (16). Results showed that compliance was better at intersections with pedestrian signals. The pedestrian signals provided useful information, and the index of hazard rate [percent of illegal start] was found to be lower at intersections with pedestrian signals. However, pedestrian-vehicular conflicts occurred on all signal phases. Table 11 contains percent of start and arrival modes in two signal conditions.

A study conducted to determine the effect of pedestrian movement on the flow of vehicles at signalized intersections utilized computer simulation (17). Two-lane and four-lane intersections were simulated, and the results revealed that pedestrians caused vehicle delay to increase. Furthermore, it was concluded that intersections that exhibit these tendencies would benefit from the inclusion of a pedestrian in the signal cycle.

In determining whether pedestrian accidents were significantly affected by the presence of pedestrian signals, data from 1297 traffic-signalized intersections in 15 cities were collected (18). Results showed no significant difference in pedestrian accidents between intersections with standard timed (concurrent walk) pedestrian signals and intersections without pedestrian signals. Exclusive timed locations were associated with lower pedestrian accidents than the other two.

Examination of behavioral data at given intersections and using limited data at urban intersections showed no significant reduction in the proportion of unsafe acts after installing pedestrian signals (19). The low number of accidents and the small number of intersections sampled did not allow for a conclusive statistical analysis.

An opinion oriented study aimed at evaluating the effectiveness of pelican crossing [Pedestrian-Actuated Crossings] was carried out (20). Surveying the general public revealed that the public lacked understanding of

Table 11. PERCENT OF START AND ARRIVAL MODES IN THE TWO SIGNAL CONDITIONS

| Arrival Mode | Without Pedestrian Signal: Start Mode | | | With Pedestrian Signal: Start Mode | | |
|---|---|---|---|---|---|---|
| | Legal | Illegal | Total | Legal | Illegal | Total |
| Successful | 69.5 | 7.5 | 77.0 | 82.9 | 6.0 | 88.9 |
| Unsuccessful | 10.2 | 12.8 | 23.0 | 2.8 | 8.3 | 11.1 |
| Total | 79.7 | 20.3 | 100.0 | 85.7 | 14.3 | 100.0 |

Source: Reference Number 16

the function of the pelican crossings, and that significant operational and design improvements must be made.

A joint American/Australian Pedestrian Conference included a discussion comparing the safety factors of zebra to pelican crossings (21). While zebra crossing caused delay and congestion in vehicle and pedestrian flow, the pelican crossings seemed to have considerable advantages. A 60% decrease in accidents was observed when a zebra crossing was changed to a pelican crossing. It was also concluded that while there is no conclusive evidence of the positive safety benefits of pelican crossings, there are no indications of adverse effects.

### 4.3 Delay, Fuel Consumption, and Capacity of Signalized Intersections

The impact of signal installation on traffic delay was evaluated (22). Results showed that signalization in general increases delay on all approaches. Furthermore, it was reported that the proportional increase in delay can be greater on the minor street at low volume levels, while the major street may experience a greater proportion at peak volume levels.

The National Signal Timing Optimization Project was initiated to provide better timing schemes with the ultimate goal of reducing delay and fuel consumption (23). The TRANSYT7F Computer program was used to develop optimized timing plans. It was reported that the average intersection can have an annual delay reductions of 15.47 hours, and an annual fuel savings of 10,524 gallons. These savings would then translate to $28,695 per intersection per year.

The TRANSYT computer model was used to time 26 intersections in Gainesville, Florida, to examine tradeoff between fuel consumption and delay (24). The study concluded that fuel savings of one gallon per hour may be achieved at each intersection without resorting to cycle lengths of unreasonable length [greater than 120 seconds]. Fuel consumption may be reduced by holding vehicles already stopped for a few more seconds to permit extra vehicles to proceed through the intersection without stopping [at the expense of increased delay].

In a recent study, the Network Simulation model [known as NETSIM] was used to evaluate some proposed system modernization (25). Measure of effectiveness produced by NETSIM was related to delay and fuel consumption. It was reported that through the use of signal optimization mechanisms, estimated benefit of $440,000 in yearly fuel consumption and $1,336,000 in delay reduction can be achieved. The study concluded that NETSIM provides a real-world view of existing and proposed traffic characteristics. Table 12 summarizes the estimated measures of effectiveness as produced by NETSIM.

### 4.4 Economics of Installing Signals

This section reports on studies that addressed all the consequences of installing signals from the economics viewpoint. A case study of political involvement was conducted, and the issue of a less than desirable traffic signal warrant was addressed (26). Before and after studies were evaluated in terms of vehicular volumes, pedestrian volumes, accidents, fuel consumption, motorist delay, and installation and maintenance costs. The "after" data, collected for one year, showed that vehicular and pedestrian volumes did not significantly increase, and that accidents experienced a small increase. Costs incurred to the public through increased accidents, fuel consumption, delay, and installation and maintenance were reported to increase by over $100,000 per year.

A study relevant to this subject attempted to analyze accident histories at intersections and tried to evaluate the effectiveness of traffic controls (27). Recognizing that accident frequency alone can be misleading, this study incorporated accident severity and type of accidents in the analysis. A utility function that includes accident type, accident severity, and unit cost per accident was developed. The study concluded that while signalization may show an increase in accident rates, this increase is offset by a reduction in the figure of merit, or "disutility" value per accident, thus leading to no significant change in total accident-related disutility.

The development of guidelines for traffic control warrants at isolated intersections was attempted in an early study (28). Both field studies and computer simulation were used to develop the warrant for intersections on high speed rural highways. Two-way stop signals, pretimed signals, semiactuated signals, and full actuated signals were evaluated over a range of traffic volumes on both major and minor approaches. Annual economic cost was used as a basis to develop criteria for selecting the most appropriate control type.

TABLE 12. NETSIM RESULTS FOR THE LUDINGTON STREET NETWORK

| Measure of Effectiveness | Existing | Proposed | % Change |
|---|---|---|---|
| Stops per Vehicle | 2.37 | 1.77 | -25 |
| Avg Speed (MPH) | 11.07 | 19.06 | +72 |
| Avg Delay Per Vehicle(s) | 133.5 | 37.03 | -72 |
| Total Delay (min) | 10,379.9 | 2953.6 | -72 |
| Hydrocarbon (g/mile) | 4.23 | 2.78 | -34 |
| Carbon Monoxide (g/mile) | 74.63 | 42.69 | -43 |
| Nitrous Oxide (g/mile) | 4.52 | 4.24 | -6 |
| Fuel Consumption (gal) | 399.77 | 282.39 | -29 |

Source: Reference Number 25

## 4.5 International Experience with Signal Installation

The accident experience of three arterial road systems controlled by coordinated signals was studied in Australia (29). Accident statistics for a nine month period preceding installation of the coordinated signal systems were compared with statistics for a nine month after period. The study shows conclusively that substantial reductions in accidents, to the extent that quite high annual rates of return on the investment by accident savings alone, are indicated. Traffic signal coordination also pays dividends in the substantial reductions of accidents even away from the points of actual control.

As an extension of the work carried out by Camkin and Lowrie (29), an investigation into approximately 15000 accidents which occurred on eight coordinated traffic signal systems in the period between the first quarter of 1968 and the third quarter of 1974 was undertaken (30). The aim of the investigation was to measure the effect of coordinated traffic signal systems. A 20 per cent improvement in the total number of accidents occurring within the systems was obtained. The major improvements occurred in pedestrian-involved and right-angle accidents. These improvements occurred without any significant change in any other accident type. When existing sites were coordinated there was a significant improvement in right-turn accidents. Therefore, it was concluded that the coordination of traffic signals can alleviate one of the major disadvantage of isolated traffic signals.

The international literature does not allow general statements regarding the effect of traffic signals on accidents at intersections. A study addressed a number of factors influencing accidents such as the 24-hour traffic volume and the number of accidents before traffic signals are installed (31). Some of the points made by this study were that the effect of the installation of traffic signals varies with road user categories and accident types. For instance, right-angle accidents generally decrease after signalization whereas rear-end accidents at best do not increase. At signalized intersections left turns comparatively often lead to accidents. Exclusive left-turn signals are therefore recommended. Other factors dealt with in the literature are: intersection layout, duration of the amber phase, switching off the installation at night, separation of traffic flow, and coordination of traffic signal installation.

Characteristics of traffic accidents and levels of traffic safety before and after signal regulation of 30 intersections in Stockholm and 10 in Goeteborg were determined and compared, and the cost benefit of signal regulation was estimated (32). The study covered 14 three-way and 26 four-way intersections signalized during the period between 1969-72. Data collected for each intersection was: geometric design and equipment, signal cycle, traffic flow, type of regulation before signalization, speed limit, signal installation and running costs, and number of accidents before and after signalization. Accidents were classified as: right-angle collisions, turning off, bumper-to-bumper, vehicle-vehicle collisions. Total right-angle collisions at both types of intersections decreased significantly. At three-way intersections, all types of accidents except rear-end accidents decreased. At four-way intersections, turning accidents increased, rear-end accidents were unchanged, and all other types decreased. The proportion of personal injury accidents was not appreciably changed, but their number decreased significantly as a result of signalization at both types of intersections. Accident cost reductions for one year were estimated to cover both signal installation cost and running costs for one year. Three and four-way intersections with a high proportion of turning traffic recorded the biggest accident reductions. Both types of intersections recorded the biggest accident reductions where none of the approaches had a special left turn lane. Four-way intersections showed a bigger accident reduction where left turns were not permitted than where they were.

## 5. FINDINGS AND CONCLUSIONS

The following is a summary of the major findings attained from the literature review:

1. For two-way stops, four-way stops, and signalized intersections, property damage accidents represented the highest severity class percentage [68%-79%], and pedestrian accidents represented a constant value of 12%.
2. Right-angle accidents was found to be the predominant type for four-way stop control intersections.
3. Accident rates at signalized intersections range between 0.55 and 2.50 accidents per million entering vehicles.

4. Most studies agreed that signal installation results in reducing right-angle accidents and increasing near-end accidents. As far as total number of accidents, no consensus was reached among studies as to how it is affected by signalization.
5. The only study that addressed signal removal concluded that converting to multi-way stop control would cause a drop in accident frequency per year. Furthermore, converting to two-way stop control would cause a reduction in both total accident and injury accident. As expected, right-angle accidents would increase and rear-end accidents would decrease.
6. Accident rates for expressways were found to be much lower than accident rates for arterials.
7. The only study that addressed signal control type and its impact on safety showed a lower number of accidents for pretimed and volume density controllers than number of accidents for actuated controllers.
8. Mixed results were observed with respect to the inclusion of a pedestrian phase in the signal cycle and its possible impact on pedestrian safety. Pelican crossings [Pedestrian-Actuated Crossings] have been proven to be a promising solution to the problem of pedestrian safety providing a good public understanding of the system.
9. Good signal timing using appropriate optimization schemes has been proven to reduce delay and excess fuel consumption.
10. Installing signals may cost the public over $100,000 per intersection per year in increased accidents, fuel consumption, delay and installation and maintenance costs.
11. The international literature showed that proper coordination of traffic signals may reduce vehicular accidents as well as pedestrian accidents.

Some conclusions can be made from the findings and they are:

1. Signal warrants, as currently outlined in the MUTCD, address the measure of effectiveness of traffic improvements individually. More specifically, the manual provides warrants for delay only, and accidents only. A composite index should be developed to

incorporate all the measures, and hence a comprehensive warrant may be developed.

2. More attention should be given to safety on arterials and proper signal coordination.
3. The effect of signal type on safety remained undocumented. Only one study provided some statistics for different signal types, and much more work is needed in this area.
4. Pedestrian signals is an area that could benefit from further research.

The next section contains four problem statements developed from the previous conclusions.

## 6. RECOMMENDED FUTURE RESEARCH

### Problem No. 1

Title:

An Analysis of Traffic Signal Warrants Based upon Multiple Measures of Effectiveness.

Problem:

The current warrants, as outlined by the MUTCD, consider selected measures of effectiveness (MOE) such as delay, accidents, and traffic flow. Other measures such as fuel consumption, equipment capital and maintenance costs, and air pollution are not treated in the manual. Modern Computer technology allows the user to evaluate complicated traffic operation strategies more effectively and cheaply than before. Several computer models exist which can simulate and evaluate MOE's of delay, user cost, fuel consumption and environmental considerations. A new set of signal warrants that combine all MOE's would be of great help for traffic engineers.

Objectives:

The first objective of this proposed research is to determine optimal threshold for installation of traffic signals and timing based on the parameters of delay, user cost, fuel consumption and pollution. The second objective is to review current relationships between accidents and signal control, then combine all MOE's into one composite index to produce traffic signal warrants.

Related Work:

National Cooperative Highway Research Program 3-20 (Unpublished) initiated this investigation, however, several study limitations and technological advances in computer models indicates a real need for more extensive and continued study.

Work Plan:

The execution of this study is proposed in two phases. The first phase addresses the determination of optimal threshold for installing and timed signals based on individual MOE's and the second phase involves the development of warrants based on combining all the measures including traffic accidents.

The following are proposed tasks for phase 1:

1. Define the operational and geometrical design characteristics of a typical isolated intersections to be evaluated. More specifically, define:
   a) Traffic volumes on major and minor streets
   b) Number of lanes per approach
   c) Traffic composition, and turning percentages
   d) Special turning lanes
   e) Traffic control (two-way stop, four-way stop, signals)
2. Review available methodologies for estimating the MOE's of interest for a wide range of operational strategies. Two methodologies are generally available; mathematical models and computer simulation. Several computer models are available for evaluating isolated signalized intersections namely: NETSIM, SOAP84, TRANSYT7F, and TEXAS. Not all these models can produce the MOE's of interest for this study. NETSIM and TEXAS are the only known programs that can treat stop controlled intersections.
3. Select the most appropriate methodology, then apply this methodology to a large number of hypothetical cases generated in task 1.
4. The results obtained from task 3 are used for two purposes:
   a) Develop optimal threshold for signal installations
   b) Develop optimal timing schemes that minimize each individual MOE.

The development of part b may involve a feedback process to task 3 to conduct more computer runs.

The proposed tasks for phase 2 are:

1. Review the literature with regard to traffic accidents at signalized and unsignalized intersections.
2. Develop relationships between operational and geometrical characteristics, outlined in phase 1, and traffic accidents. These relationships should at least address accident types and accident severity. The purpose of developing these relationships is to be able to estimate accident number or accident rate for a given traffic volume and control type.
3. Develop a utility function that combines all MOE's of phase 1 and accidents. The index estimated from the function can be based on economic measures (annual cost) or it can be a weighted factor. Regardless of the units of this index, the final stop would be to develop warrants for signal installation that minimize the developed index.

Duration & Cost:

Phase 1: 15 months for $90,000

Phase 2: 9 months for $60,000

Implementation:

Refinements of presents traffic signal warrants offer the opportunity for minimizing delay and fuel consumption and a utility function as justification for installation or modification. Computer capabilities offer almost unlimited methodology for analysis of each proposed traffic signal installation.

Problem No. 2

Title:

Accident Reductions Using Signal Coordination on Arterial Streets.

Problem:

Signal coordination has been known to provide a better traffic flow on arterial streets. Benefits accrued from smoother traffic movements are less delays, less fuel consumption and emission, and possible improvement in traffic safety. Very limited research has been conducted in the U.S. to support this hypothesis, and a study is needed to test this hypothesis and quantify, if possible, the reduction in accident rates due to signal coordination.

Objective:

The main objective of this study is to study the possible effect of signal coordination on accident statistics and accident patterns.

Related Work:

Two studies conducted outside the U.S. that addressed this topic and they were reviewed in the literature research section of this report.

Work Plan:

The following tasks are proposed for this study:

1. Before and after studies are proposed to conduct this research. At least four arterials with different geometric and operation characteristics need to be selected. These sites should meet the following requirements:
   a) No major changes in land use along the arterial during the study period.
   b) No alterations of street (other than regular maintenance) during study period.
   c) Homogenous cross sections of the arterial.
2. Collect accident data from the selected sites during the before period (before signal coordination) as well as during the after period. The minimum duration for the before and the after periods should be two years.
3. Conduct statistical analysis (regression analysis, and/or analysis of variance) to test the hypothesis that signal coordination reduces traffic accidents.

Duration & Cost:

12 months for $80,000.

Implementation:

The statistical relationships developed will provide traffic engineers with a better understanding of the safety aspect on arterials. Guidelines for arterial street coordination may be developed to maximize safety.

Problem No. 3

Title:

An Analysis of Traffic Accidents for Different Signal Control Types.

Problem:

A large number of signalized intersections are timed and treated as isolated intersections in this country. Signalized isolated intersections may have any of the known type of controllers (pretimed, actuated, demand responsive, and green extension system). It is not yet clear as to how these controllers affect traffic safety at intersections.

Objective:

The objective of this study is the efficiency of different types of signal controllers in terms of traffic safety.

Related Work:

To the best of our knowledge, no study has addressed this issue. The National Cooperative of Highway Research Program, report number 233, provides some guidelines for selecting a traffic control for an isolated intersection. The selection process was aimed at traffic delay and hardware cost and reliability, and the safety aspect was not addressed in detail.

Work Plan:

A large data collection effort coupled with statistical analyses are needed to successfully carry out this study. Some basic tasks are outlined:

1) Design a statistical experiment for accident data collection. Minimum sample size need to be estimated for number of intersections per control type and number of accidents classified by type and severity.
2) Select a number of isolated intersections that would satisfy the maximum number determined in the design of experiment and try to have them geographically distributed over the whole state. For each site, the following information needs to be collected at minimum:
   a) Traffic volume
   b) Traffic composition
   c) Turning percentages
   d) Geometric design data
   e) Signal control type, and timing plans
   f) Accident number classified by type and severity
   g) Approach speed
3. Conduct statistical analyses (using regression analysis and/or analysis of variance) to test the possible impact that different types of signal controllers have on accidents.

Duration and Cost:

9 months for $60,000.

Implementation:

The statistical analysis results will shed light on the safety aspect of selecting control types at isolated intersections. General guidelines may be developed to assist traffic engineers with their decision. The MUTCD has some general guidelines with regard to this issue, and this study could refine these guidelines.

Problem No. 4

Title:

Pedestrian Signals: Warrants and Effectiveness

Problem:

Although the literature is full of studies related to pedestrian safety, only few of these addressed pedestrian signals in particular. The inclusion of a pedestrian in a signal cycle would certainly increase vehicular delay and vehicle operating costs. It is not well documented through how much pedestrian safety is gained by adding the pedestrian phase.

Objective:

The objective of this study is to investigate the effectiveness of pedestrian accidents and the warrants for pedestrian phase schemes.

Related Work:

The literature review section of this report contains information about previous effort related to this topic. The MUTCD outlines the signal warrant based on pedestrian flows in general terms.

Work Plan:

The proposed tasks are:

1) Design a statistical experiment for pedestrian accident data collection. Minimum sample sizes for number of intersections and number of accident can be estimated.
2) Select the sites needed for data collection, and for each site gather the following information:
   a) Vehicular and pedestrian volumes
   b) Traffic composition
   c) Turning percentages
   d) Geometric design data
   e) Signal timing parameters
   f) Approach vehicular speed

3) Conduct statistical analyses to correlate pedestrian accidents to pedestrian signals and other relevant parameters.

4. Using computer simulation, vehicular delay and extra user costs are estimated due to introducing a pedestrian signal phase in a cycle.

5. Pedestrian signal phase warrants are developed using the accident information developed in task 3 and the other MOE's assessed in task 4.

Duration and Cost:

12 months for $80,000

Implementation:

Refinement of present traffic signal warrants will provide traffic engineers with better guidelines based on accident data. Better understanding of the needs of pedestrian phasing will be provided.

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